Integrated Sequential Anoxic Aerobic (ISA) Reactor for Organic Matter and Nutrient Removal from Wastewater

by

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CERTIFICATION OF APPROVAL

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(CIVIL)

Approved by,

_____

(Associate Professor Dr. Mohammed Hasnain Isa)

UNIVERSITI TEKNOLOGI PETRONAS TRONOH, PERAK

MAY 2014

CERTIFICATION OF ORGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or person.

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(Khairzrul Haikal Bin Mohd Khairul)

ABSTRACT

The removal of nitrogen and organic matter using an integrated single reactor composed of aerobic and anoxic zones has been a common focus in this investigation. This study aimed to develop a novel Integrated Sequential Anoxic-Aerobic (ISA) reactor for organic matter and nutrient removal and assess the performance in terms of organic matter and nitrogen removal with respect to different reactor configuration. Two identical reactors was fabricate using clear acrylic Perspex with maximum working volume of 5.5*L*. It is operated under continuous aeration maintaining 2mg/L of dissolved oxygen (DO) in aerobic zone and internal recycle rate of three times the influence flow rate with hydraulic retention time (HRT) of 24 hours. Two different location of influence flow into the reactor were tested in two difference phase (Phase 1 and Phase 2) which low and medium strength of untreated domestic wastewater characteristic is used. Reactor A influence will enter through the aerobic part while Reactor B is through the anoxic part of the reactor.

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LIST OF ABBREVIATIONS

Anammox	Anaerobic Ammonium Oxidation
AOB	Ammonia Oxidizing Bacteria
BOD	Biochemical Oxygen Demand Biochemical
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DOE	Department of Environment
F/M	Food mass ratio
HRT	Hydraulic Retention Time
ICS	Intelligent Controlling System
ISA	Integrated Sequential Anoxic-Aerobic
IVMBR	Integrated Vertical Membrane Bioreactor
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
N	Nitrogen
NOB	Nitrite Oxidizing Bacteria
OECD	Organisation for Economic Co-operation and Development
P	Phosphorus
SRT	Solids Retention Time
S_o	Influent concentration
S_e	Effluent concentration
SBBR	Sequencing Batch Biofilm Reactor
TN	Total Nitrogen
TP	Total Phosphate
UTP's STP	Universiti Teknologi PETRONAS Sewage Treatment Plant
VSMBR	Vertical Submerged Membrane Bioreactor
X_v	MLVSS in steady state

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Conventional domestic sewage treatment plants usually involve biological treatment process (Xiuhong, et al., 2007). It mainly consist of two separated tank which provide different environments of aerobic and anoxic zones (Moura, et al., 2012) organic matter and nutrient removal takes place **(Fig. 1)**.

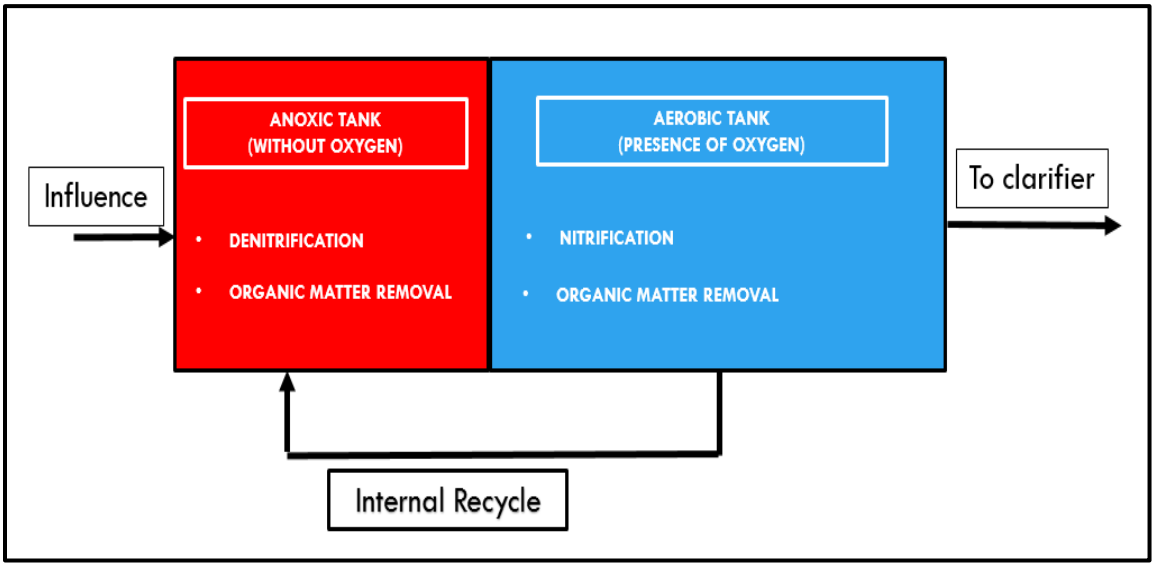

Figure 1.1 Typical mainstream biological preanoxic reactor

Organic matter removal involve both aerobic and anoxic oxidation process (Metcalf & Eddy, Inc., 2013). The process of biological decomposition, oxidation and synthesis will occur simultaneously with the sufficient presence of oxygen and organic waste. The organic waste is consumed to obtain energy which will be used for cell maintenance and generation of new cells. Lastly, when all the organic matter is consumed, the bacteria will undergone endogenous respiration process where it consumes own cell to obtain energy for cell maintenance.

Furthermore, nutrient also is consumed for cell synthesis and growth. This include principal inorganic nutrient such as Nitrogen (N), Sulfur (S), Phosphorus (P), Potassium (K), Magnesium (Mg), Calcium (Ca), Iron (Fe), Sodium (Na) and Chlorine (Cl) (Metcalf

& Eddy, Inc., 2013) and minor nutrients like Zinc (Zn), Manganese (Mn), Molybdenum (Mo), Selenium (Se), Cobalt (Co), Copper (Cu) and Nickel (Ni) (Madigan,et al., 2000).

Basically, nitrogen removal can be classified into three type of major processes which involve physical, chemical and biological process (Halling-Sorensen & Jorgensen, 1993). The most common alternative used for low strength domestic wastewater is by removing nitrogen biologically. This is due to the fact that this method relatively effective and economical (Carrera et al., 2003) but not for the high strength industrial wastewater as the nitrification process can be inhibit by high concentration of ammonium or nitrite (Anthonisen et al., 1976).

Conventional biological nitrogen removal method follows two-step process of nitrification through autotrophic oxidation which convert ammonia to nitrite and then to nitrate. While denitrification through heterotrophic reduction which reduces nitrate to nitrogen gas (Ding et al., 2013; Yao et al., 2013). The processes of nitrification and denitrification will occur in two separate independent units of aerobic and anoxic reactor respectively.

The conventional processes employed in various domestic sewage treatment plants currently are not able to meet the recent amendment of the Environmental Quality (Sewage) Regulations 2009 as the nitrification is inhibited due to insufficient solids retention time (SRT) and sludge age of the biomass (Kutty, et al., 2011). According to Rafael et al. (2012), for the removal of carbon and nitrogen, the conventional treatment system "needs three treatment units, which increases the construction costs of the treatment system" (p. 163). In addition, conventional treatment plants use almost 60-65% of total energy consumption for aeration process (Duchene, et al., 2001; Rieger, et al., 2006). The DO concentration provided during the aeration process may not be cost-effective in producing acceptable effluent quality.

1.2 Problem Statement

The discharge of organic matter and various nutrients has been noticed to be harmful to aquatic life (Ding, et al., 2013). Organic matter will reduce dissolved oxygen in the area while nutrient will stimulate harmful algal blooms and eutrophication. Due to the short life span, the decomposition of the large number of dead algae will consume a lot of dissolved oxygen. Hence, it will also lead to oxygen depletion and causing the death of aquatic life in the affected area (El-Bourawi et al., 2007; Tan et al., 2006). Moreover, some species of algae may even produce neurotoxins which can cause severe health problems to humans in high concentration (Goldstein & Peterson, 2006).

It has also been found out that nitrogen in the form of nitrite is one of the primary contaminants in water which may cause blue baby syndrome during their first 6 months. In addition, prolonged exposure to nitrate-contaminated drinks may lead to diabetes, thyroid disease and cancer. (Knobeloch et al., 2000)

On the other perspective, the conventional sewage treatment plant currently operating in series of different treatment units in providing different environment conditions for the nitrification and denitrification process which consequently require a long retention time or large volume in completing the nitrogen removal process (Lee et al., 2001). This also lead to the construction of a number of treatment units, which increases the construction cost of the treatment system (Rafael et al., 2012). Besides, conventional treatment plant use almost 60-65% of total energy consumption for aeration process (Duchene, et al., 2001; Rieger, et al., 2006) yet the process is not controlled optimumly which resulting in high operational cost.

In protecting the environment, maintaining and improving the water quality in Malaysia, the Department of Environment (D.O.E.) Malaysia has implemented the revised *Environmental Quality (Sewage) Regulations 2009* in December 2009 which significantly lowered the bar of maximum discharge limit of various parameters in Malaysia. However, insufficient solid retention time and sludge age inhibit the nitrification process (Kutty, et al., 2011) itself. As a consequence, an unacceptable effluent quality is discharge to the water body. Even though a variety of methods have

been developed in enhancing nitrogen removal, yet none had been demonstrated to provide a simple, effective and consistent effluent quality (Washington State Department of Health, 2005).

1.3 Objectives

I. To develop a novel biological reactor for organic matter and nutrient removal.

II. To assess the performance of the reactor in terms of organic matter and nitrogen removal.

III. To evaluate the application of two reactor configuration on the removal efficiency of organic matter and nitrogen removal.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 Wastewater Treatment

Wastewater treatment is known as a process of managing wastewater and reducing its contaminants to acceptable levels for discharging it back to the environment (Anglin, 2014). Generally, the treatment process can be divided into three stages called the primary, secondary and tertiary treatment. Primary treatment involves removal of a portion of suspended solid and organic matter from wastewater through settling or filtration while secondary treatment is where the removal of biodegradable organic matter and suspended solid take places and, tertiary treatment is the removal of residual suspended solids and nutrients (Metcalf & Eddy, Inc., 2013).

The main objective in wastewater treatment is always the removal of organic matter and nutrient. The organic matter discharge into the environment will reduce the dissolved oxygen and affect the aquatic life. While excessive nutrient discharge into the water body is harmful to animals and human if consumed regularly.

According to the subsidiary regulation of the Malaysian Environmental Quality Act 1974, Environmental Quality (Sewage) Regulation 2009 the discharge limit can be divided into two standards; Standard A is when the discharge of wastewater is into any inland water within catchment areas specified in the Third Schedule while Standard B implies the discharge to any other inland waters or Malaysian Water. Following is the acceptable condition of sewage discharge according to Second Schedule of Environmental Quality (Sewage) Regulation 2009 presented in **Table 1.1**.

Table 1.1 Acceptable Condition of Sewage Discharge of Standards A and B of New Sewage Treatment System

Parameter		Unit	Standard	
			A	B
(1)		(2)	(3)	(4)
(a)	Temperature	^{o}C	40	40
(b)	pH Value	-	6.0-9.0	5.5-9.0
(c)	BOD5 at 20°C	mg/L	20	50
(d)	COD	mg/L	120	200
(e)	Suspended Solids	mg/L	50	100
(f)	Oil and Grease	mg/L	5.0	10.0
(g)	Ammoniacal Nitrogen (enclosed water body)	mg/L	5.0	5.0
(h)	Ammoniacal Nitrogen (river)	mg/L	10.0	20.0
(i)	Nitrate - Nitrogen (river)	mg/L	20.0	50.0
(j)	Nitrate - Nitrogen (enclosed water body)	mg/L	10.0	10.0
(k)	Phosphorous (enclosed water body)	mg/L	5.0	10.0

2.2 Organic Matter Removal

Organic matter removal involves both aerobic and anoxic oxidation processes (Metcalf & Eddy, Inc., 2013). The process of biological decomposition, oxidation and synthesis will occur simultaneously with the sufficient presence of oxygen and organic waste. The organic waste is consumed to obtain energy which will be used for cell maintenance and generation of new cells.

$$COHNS + O_2 + bacteria \rightarrow CO_2 + H_2O + NH_3 + other\ end\ product + energy \quad \textbf{(2.1)}$$

$$COHNS + O_2 + bacteria + energy \rightarrow C_5H_7NO_2 \text{ (New cells)} \quad \textbf{(2.2)}$$

Lastly, when all the organic matter is consumed, the bacteria will undergone the endogenous respiration process where it consumed own cell to obtain energy for cell maintenance.

$$C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + NH_3 + 2H_2O \quad \textbf{(2.3)}$$

For anoxic oxidation, the heterotrophic bacteria requires BOD and oxygen for food.

$$BOD + NO_3^- + bacteria \rightarrow N_2 + OH^- + energy \quad \textbf{(2.4)}$$

The C/N ratio plays an important roles in effluent quality Low carbon ratio may result in low efficient total nitrogen removal efficiency due to poor denitrification which can be observed frequently in wastewater treatment system with low C/N ratio (Chen et al., 2013). This promote the growth competition between the autotrophic and heterotrophic bacteria. (Carrera, 2003).

2.3 Nitrification and Denitrification

Chemical Oxygen Demand (COD) and nitrogen removal through biological processes is usually preferred as they require less cost, energy and chemicals in comparison to physical-chemical treatment (Carrera et al., 2003; Vaiopoulou et al., 2007). This is due to the fact it is less expensive, effective and environmental friendly. The treatment usually involves a two-stage process, nitrification and denitrification, which will occur in two separate reactors (Moura et al., 2012).

Nitrification is the process of converting ammonia-nitrogen in the wastewater to nitrate-nitrogen by ammonia oxidizing bacteria (AOB). This process will occur in the aerobic reactor where there is a presence of dissolved oxygen for the autotrophic bacteria. In this stage, by utilizing the oxygen that is supplied, bacteria converts ammonia-nitrogen into nitrate-nitrogen. This is shown in the steps below:

$$NH_4 + O_2 \xrightarrow{Nitrosomonas} H^+ + H_2O + NO_2^- + E \quad \textbf{(2.5)}$$

$$NO_2^- + O_2 \xrightarrow{Nitrobacter} NO_3^- + E \quad \textbf{(2.6)}$$

The Nitrosomonas bacteria is responsible for the conversion of ammonia-nitrogen into nitrite-nitrogen. This nitrite-nitrogen is then converted into nitrate-nitrogen by the bacteria Nitrobacter which is also known as the nitrite oxidizing bacteria (NOB). Autotrophic bacteria generally have slow growth rates and require long retention time and they mainly depend on the temperature of the wastewater and dissolved oxygen present (Yao et al., 2013; Muller et al., 2003; Jetten, et al., 1997; Moura et al., 2012). If they are not given enough time, there is a risk of wasting them out of the system and losing nitrification. Likewise, if there is no dissolved oxygen present, nitrifiers can be

completely inactive. Also, the nitrifiers are sensitive to pH and will function optimally in pH range of 7.5 to 8.6 (Yoo, et al., 1999).

The nitrate-nitrogen is then transported to the anoxic reactor for denitrification. Denitrification process is performed by heterotrophic bacteria under specific conditions. Heterotrophic bacteria need BOD as a source of food and oxygen for oxidizing it. So by limiting the dissolved oxygen in the wastewater, heterotrophic bacteria will try to find other alternative, for example by stripping oxygen present in nitrate optimally in pH ranging from 7-8 (Yoo, et al., 1999). It will basically produce energy, base and nitrogen gas (Yao et al., 2013).

$$BOD + NO_3^- \xrightarrow{Bacteria} N_2 + OH^- + E \quad \textbf{(2.7)}$$

The internal recycle of the nitrification and denitrification process is to ensure a complete nitrogen removal can be achieve. The recycle not only maintaining pH of both zone, but it also providing alkalinity for aerobic zone that been produce in the anoxic part.

2.4 Past Studies

Numerous researches have been carried out in improving the conventional wastewater treatments. This includes the research carried out by Char et al. (2008) who developed a Vertical Submerged Membrane Bioreactor (VSMBR) combining anoxic and aerobic zones with membrane filtration into one reactor. The research is further improved by An et al. (2013), produced a novel Integrated Vertical Membrane Bioreactor (IVMBR). VSMBR is exposed to a low strength wastewater characteristic with COD of 120-300mg/L, N of 30mg/L and 6mg/L of P. The removal efficiency of COD, TN and TP of the reactor are 95%, 75% and 71% respectively. While IVMBR using wastewater characteristic of COD of 220±37mg/l, TN 52.7±4.7mg/l and TP of 4.6±0.9mg/l produced a removal efficiency of 94.2±1.3%, 13.3% and 20.0% respectively.

However, membrane bioreactors have a crucial disadvantage. They involve higher capital cost in comparison to the conventional treatment plant due to the existing of membrane unit and sophisticated equipment used. Moreover, membrane fouling with

respect to filtration time may occur, thus a higher maintenance cost may be experienced. Aeration cost may also increase due to achieving hydrodynamic scouring effect to clear any blockage at the membrane by pumping lots of air into the reactor (Yao, et al., 2013).

Research by Ding et al., (2011), using COD/N ratio of 12.5 with influents characteristics of COD of 448mg/L, NH_3 −N of 32mg/L and TN of 36mg/L inside a sequencing batch biofilm reactor (SBBR) controlled by an intelligent controlling system (ICS) manage to produce removal efficiency of COD of 95%, NH_3 −N of 90% and TN of 87% at an HRT of 7 hours. This studies shows that SBBR controlled by the ICS have a potential for an effective treatment for domestic sewage.

Nonetheless, even though Ding et al., (2011) showing a good performance in term of removal efficiency, but the usage of sophisticated intelligent controlling system increase the capital cost of the reactors. In addition, the maintenance cost of the system also needs to be considered. However, this reactors may be a good alternative to be used for high ranges of influents concentration sewage treatment plants since the reactor shows a good removal performance for influent ranged from 222.21mg/l up to 1565.90mg/L.

In another research conducted by Yao et al., (2013), they using heterotrophic nitrifying-aerobic denitrifying bacteria in their reactor. Wastewater characteristic of COD ranging from 600mg/L to 700mg/L and N$H_4^+ - N$ of 50-70mg/L is tested which produced 96% and 77.5% removal efficiency respectively. As for the studies by Du et al. (2014), they used anaerobic ammonium oxidation (Anammox) bacteria inside the sequencing batch reactor. The wastewater using a C/N ratio of 1, 2 and 4 where N is kept in range of 30-40mg/L. The optimum removal efficiency TN of the study shows that 97.47% was realized at C/N ratio of 2.

Nevertheless, the different microorganism used have its own disadvantages. The study by Yao et al., (2013) using the aerobic denitrifying bacteria in the reactor give them the advantage as the denitrifying bacteria will not be suppressed due to the tolerance to oxygen. However, this does not compliment with this research objective in producing an effective yet low capital and operational cost as the reactor needs constant and large supply of aeration. As for the Anammox bacteria, it had been noted that it have an

extremely slow growth rate with a double time of approximately two weeks (Du, et al., 2014; Strous et al., 1998). From the latest study by Du et al. (2014) the Anammox was also noticed to be inhibited under high organic matter which resulted in the TN removal efficiency drop. The study shows that by increment of the C/N ratio of 4, the TN removal efficiency drop more than 20% rapidly, producing a removal efficiency less than 70%. Thus, further study are needed to determine the true nature of Anammox before the application of it can be establish in a reactor.

CHAPTER 3

METHODOLOGY

3.1 Reactor Configuration

The idea of the reactor is to integrate the anoxic and aerobic tank vertically. Two identical cylindrical-shaped main body is fabricated using acrylic with an internal diameter of 96mm, and a total volume of 5.8L (5.5L working volume) instead of rectangle-shaped is to prevent the clusters of bacteria stuck at the edges of the corner **(Fig.4.1)**. Round-shaped interior of reactor allows smooth movement of bacteria and also the wastewater.

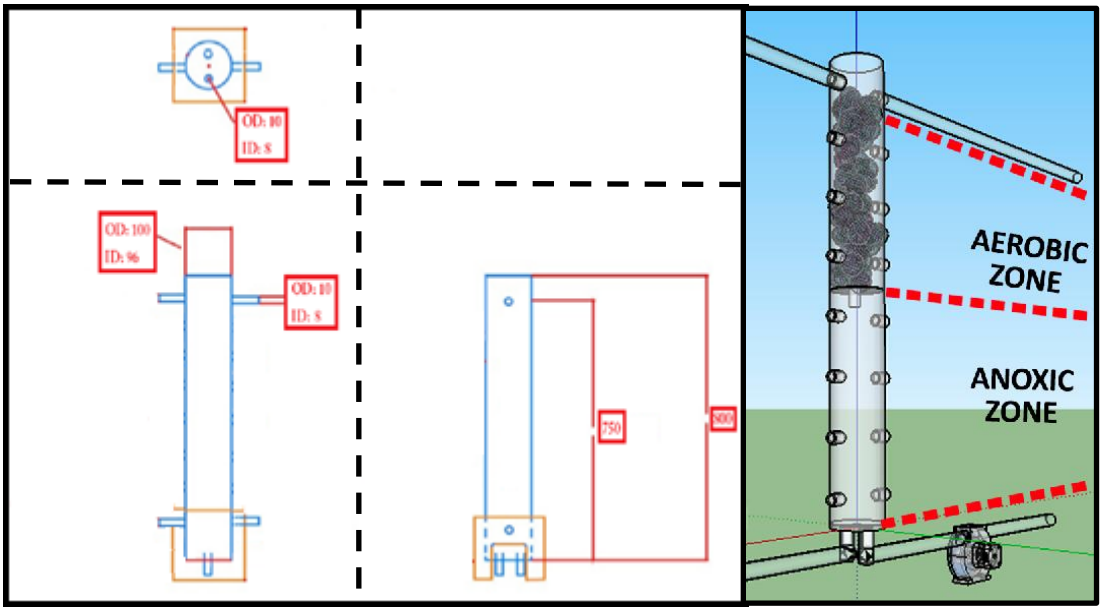

Figure 3.1 Orthographic Design Concept View and 3D Drawing of Actual Prototype

The air is supplied to the system using aquarium aerator, Shanda SD-200 with maximum dual output of 2L/min. Porous stone is used as the air diffuser is position at the middle of the column which will provided only the upper part of the reactor with dissolved oxygen, thus creating almost anoxic condition at the bottom part of the reactor. The aerobic part is filled with bio-ball with diameter of 3.5cm with porosity of 0.92 to promote attached growth. The sludge used in this studies is taken from the Universiti

Teknologi PETRONAS Sewage Treatment Plant (UTP's STP). The startup period is designed to be around 15days.

In Reactor A, the inlet of the influence is set to be at the anoxic zone **(Fig.3.2a)** while Reactor B is on the aerobic zone of the reactor **(Fig. 3.2b)** with same flow rate of 5L/day . Both of the reactor topmost outlet is connected to the bottom most to create internal recycle from nitrification towards the bottom outlet for denitrification process with flow rate of 15L/day. Moreover, the upward flow created by the recycle will act as a mixer in the anoxic zone. Feeding and recycle circulation are conducted by peristaltic pump. The remaining outlets are used for sample collection at regular interval for monitoring of the parameter.

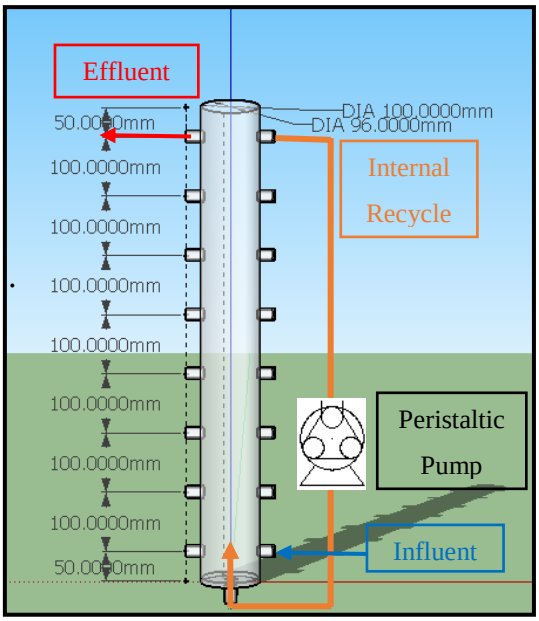

Figure 3.2a Typical Process of Reactor A

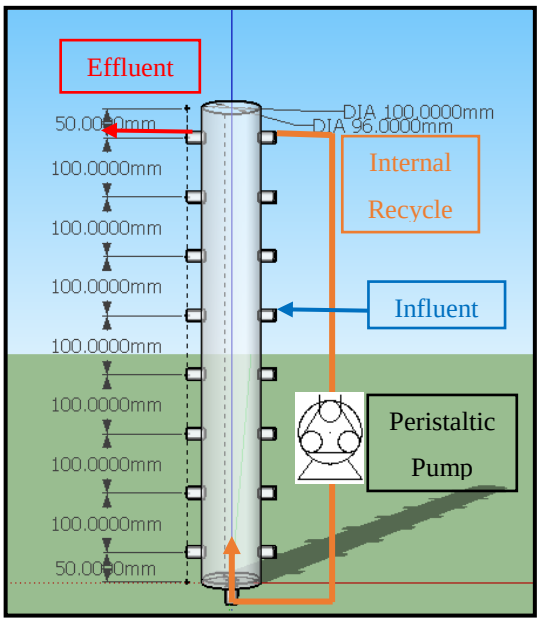

Figure 3.2b Typical Process of Reactor B

3.2 Synthetic Wastewater

Organisation for Economic Co-operation and Development (OECD) synthetic wastewater is used for the reactor. The composition is listed in the following **Table 3.1**. The medium produced from the mixture having pH around 7.5±0.5 and COD of 27,000mg/L differ from the result obtained by Karahan(2010) where he obtained a stock with COD of 13,360mg/L. Once prepared, the substrate is stored in the dark at 0°C to 4°C, for no longer than 1 week to prevent from fermentation. This stock solution is

roughly 100 times as concentrated as domestic sewage. The stock solution will be suitably diluted and fed to the reactor for treatment evaluation.

Table 3.1 Composition of Influent

C-SOURCE	N-SOURCE	P-SOURCE	OTHERS
PEPTONE (16g)	UREA (3g)	K_2HPO_4 (2.7g)	$NaCl$ (0.7g)
MEAT EXTRACT (11g)			$CaCl_2$ (0.4g)
			$MgSO_4$ (0.2g)

3.3 Reactor Operation and Monitoring

The reactor is operated under continuous aeration with HRT of 24h to promote nitrifying aerobic microorganisms. The influent flow rate is set to be 5L/day with internal recycle rate of 3Q of the influence rate (15L/day) with SRT of 25 days. Phase 1 and Phase 2 will introduce both Reactor A and Reactor B with low and medium strength synthetic wastewater of 250mg/l and 500mg/l respectively.

The parameter monitored will includes DO, pH, mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), COD, Nitrate, Ammonium-nitrogen and Phosphorus. All the monitoring will be in accordance to the American Public Health Association (APHA) 2005, Standard Methods for the Examination of Water and Wastewater. As the reactor using a synthetic water, the feed will be mostly soluble. Since the scope of study does not include clarifier, a high value of COD to be expected in effluent cause by the microorganism that flows out during samples collection. Thus, the sample will be filtered first to before the parameter is determine. In actual treatment plants, this matter is out of concern since there is an existence of clarifier.

The dissolved oxygen at the aerobic zone where nitrification process will occur is maintained at 2mg/L. This is to ensure that during recycling of the “nitrified” water to

bottom part of the reactor, the dissolved oxygen is almost 0mg/L to encourage effective denitrification process. Thus this parameter will be observe every day to ensure enough DO supply of 2mg/L at the aerobic zone.

The pH level and alkalinity of the aerobic zone also will be monitored. This is to encourage effective nitrification process; pH reflect the hydrogen-ion concentration. The pH level will be around 8 ± 0.5. Alkalinity also will be monitored. It is mainly from the presence of the hydroxide, carbonates and bicarbonates ion. The alkalinity is important to buffer the treatment process and nutrient removal. The MLSS also will be monitored once every two week to be around design value of 2200mg/L. This is to ensure enough microorganism inside the reactor and not been wash out completely or experiencing endogenous respiration.

The soluble COD value also will be monitored. COD reflect the amount of organic matter in the wastewater. The typical result for COD should be in decreasing manner. While nitrate is the product of conversion of ammonia by autotrophic bacteria. Nitrate is to be removed from the system via denitrification process. It is removed through conversion to nitrogen gas which bubbles its way to the top of the reactor and diffuses out to the atmosphere. Since nitrogen is a harmless gas, there is no impact to the surrounding compared to what caused by ammonia in water. Nitrate concentration in the sample also should be decreasing.

Ammonium-nitrogen concentration will be monitored. It is the main component to be removed. It is removed through nitrification process which occurring in aerobic environment. In a proper functioning reactor, the concentration should be decreasing. This is because the ammonia is being converted to nitrates, thus indicating the lower ammonia level. As for phosphorus, the concentration is expected to be consistent throughout the experiment due to the fact that the reactor is designed mainly for nitrogen removal. If there is any decrease in phosphorus, it is cause by the consumption of bacteria as a necessary nutrient.

3.4 Analytical procedure

The removal efficiency and organic loading rate for both reactor will be evaluate throughout the studies. The comparison of influent and effluent of both reactor will be tabulate and compared.

To illustrate the mathematical model of the activated sludge, kinetics expressions is used. The fundamental is to keep the influent at steady-state and system to stabilize before comparing the influent and effluent. The concentration of MLVSS also is needed as for representation of the bacteria.

$$Efficiency = \frac{Influent - Effluent}{Influent} \times 100 \quad \textbf{(3.1)}$$

$$Organic\ Loading\ Rate = \frac{QS_o}{V} \quad \textbf{(3.2)}$$

3.5 Project Milestone/Gantt Chart

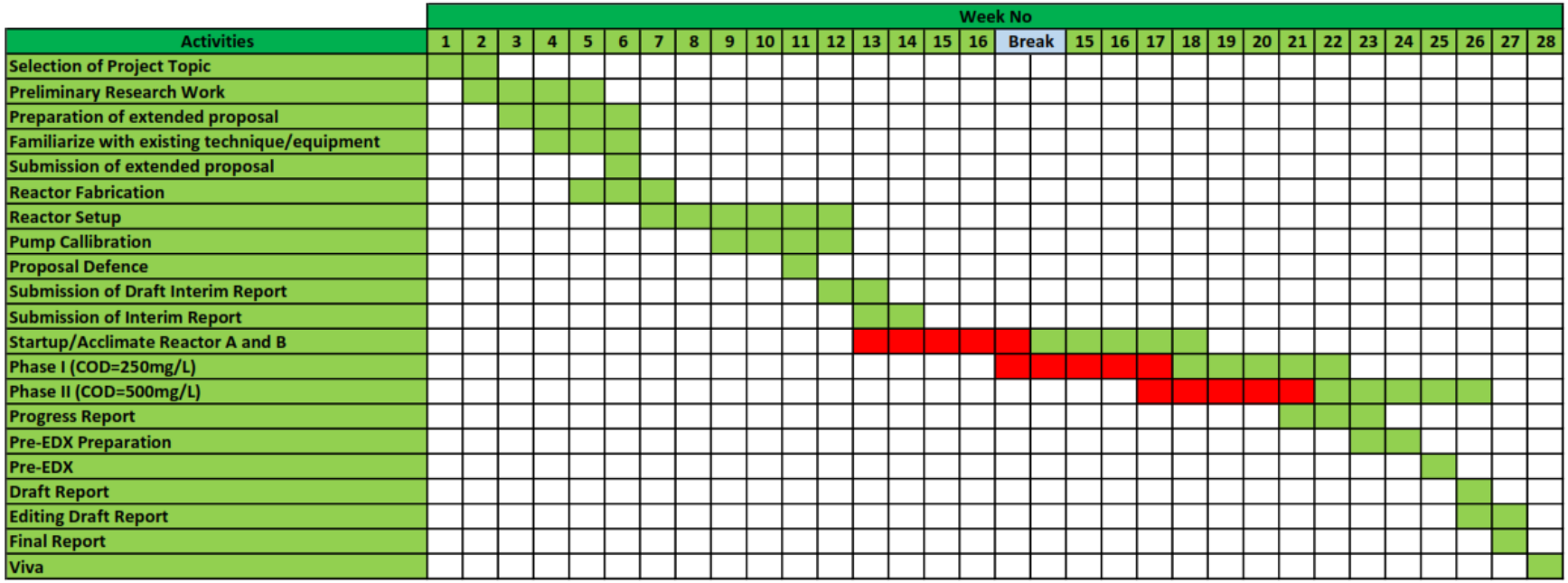

Figure 3.3 Gantt Chart

Table 3.2 Milestones of the Project

No	Milestones	Date	No	Milestones	Date
1	Reactor Startup	4th April 2014	**4**	Result Analysis and Progress Report	7th July 2014
2	Phase 1	5th May 2014	**5**	Final Report	11th August 2014
3	Phase 2	7th July 2014			

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Reactor Fabrication and Setting up

Two identical reactor were fabricated using acrylic Perspex. The dimensions are shown in **Figure 3.1**. **Figure 4.1** is the fabricated reactor. Some of the challenges faced during the fabrication was minor leakages occurring at the joint of the inlet. However, the problem did not hinder the planned program.

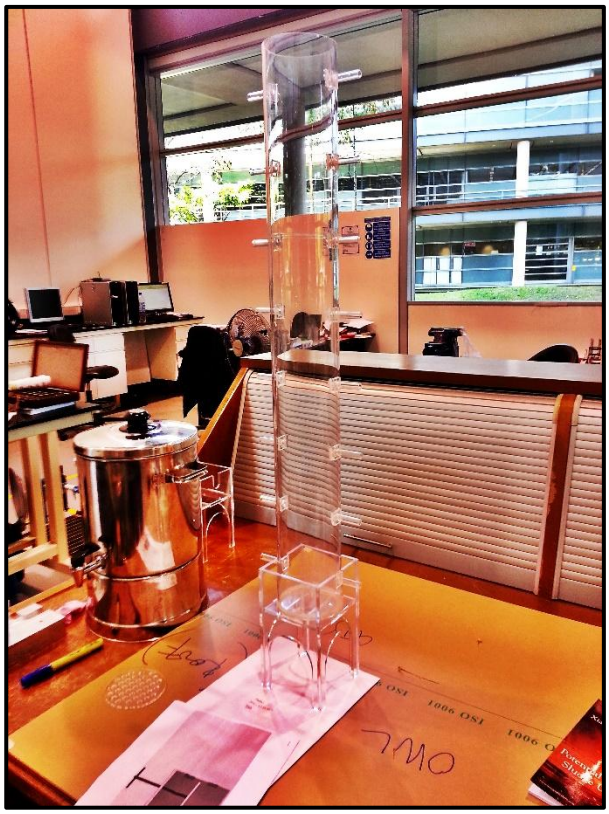

Figure 4.1 Fabricated Reactor

In Reactor A, the influent feed inlet was set at the aerobic zone **(Fig. 3.2a)** whereas Reactor B was set on the anoxic zone of the reactor **(Fig. 3.2b)**. This is to investigate the removal efficiency achieved at different configuration.

Figure 4.2 Setup of Reactor

The pumps were calibrated to ensure accurate hydraulic loading is applied to the reactors daily. The influent flow rate is set at 5 L/day with internal recycle rate of of the influent rate 15 L/day.

4.2 Reactor Startup

The acclimatization period was started on 20th May 2014 with aerobic and anoxic sludge, taken from Universiti Teknologi PETRONAS Sewage Treatment Plant (UTP's STP). At first, the aerobic sludge was put into a different container with bio-balls to promote attached growth with a constant supply of oxygen and substrate. While anoxic sludge was instantaneously poured into the reactor and the influent and effluent soluble COD concentration was monitored to ensure the presence of the bacteria. After three days, the NOB bio-balls is setup into the reactor and the complete reactor operation

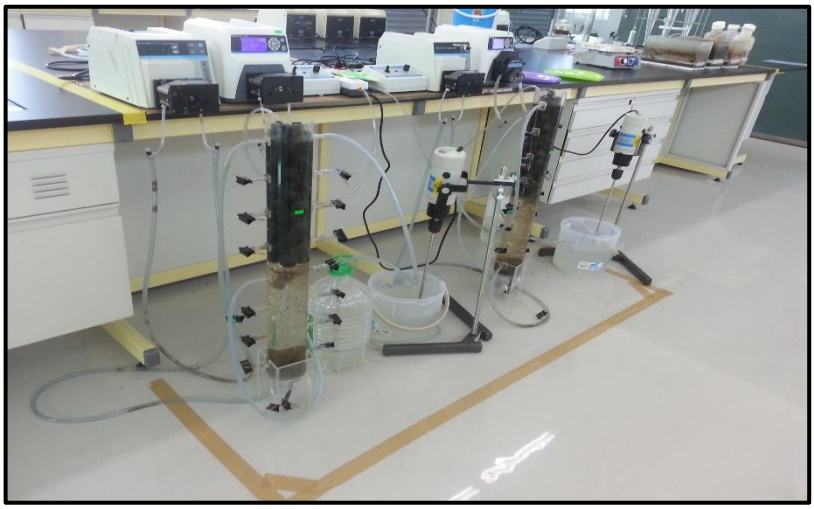

Figure 4.4 Reactor Startup

started immediately **(Fig 4.4).**

During the first day of the startup period, a more diluted influent was supplied to the reactors to ensure most of the uncontrolled variable taken from UTP's STP is consumed. Then COD concentration of around 250mg/L was applied constantly **(Table 3.1)**. A high removal efficiency was noticed after seven days for both reactor due to the effective acclimatization of biomass to the reactors.

4.3 Performance Monitoring

4.3.1 Organic Substance Removal

Both Reactors A and B were fed with the same influent composition. However, the effluent quality differed. From day 1 to day 7 during the acclimation period, the reactor removal efficiency of COD improved constantly and both Reactor A and B was noticed to produce a consistent COD removal during that period. Then, Phase 1 experimental

research was started with average organic loading of 262 mg/day. After 25 days, Phase 2 commenced (Day 32) with influent COD average organic loading of 508.76 mg/day **(Fig 4.4)**.

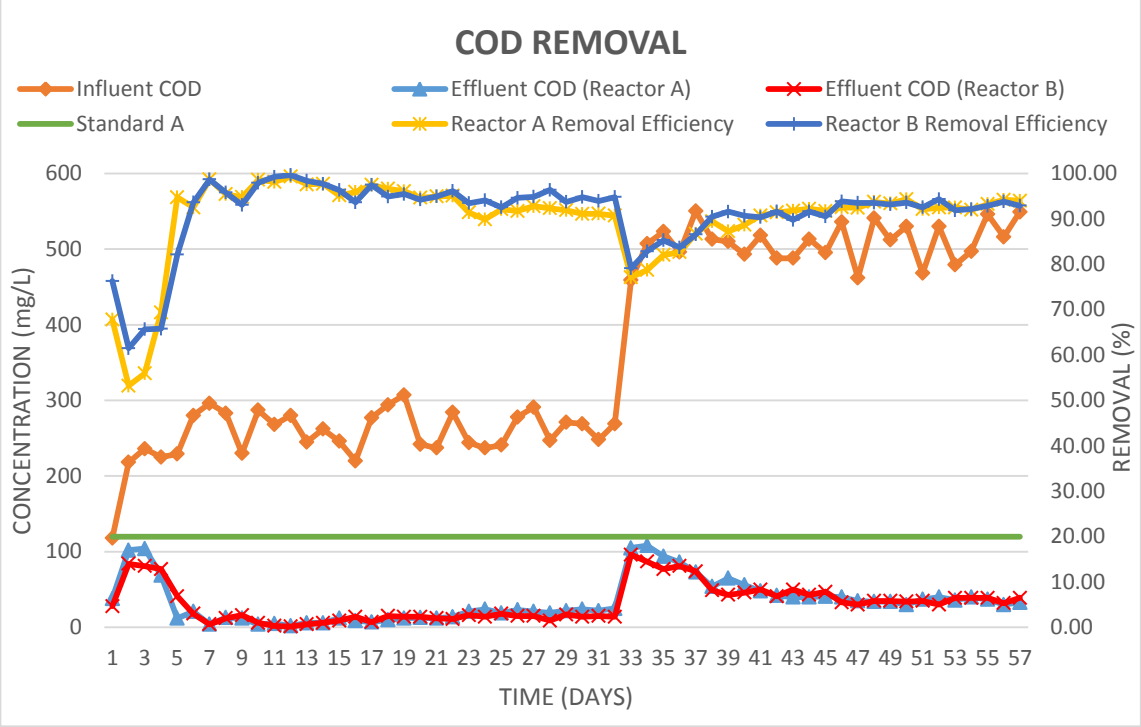

Figure 4.4 COD Removal

Figure 4.4 shows the graph of influent and effluent concentrations and removal efficiencies of COD versus time for the whole research. The full data can be refer at **Appendix A**. It was observed that Reactor A reached the steady state (5th day) faster than Reactor B (7th day). For Phase 1, Reactor A have an average COD removal of 94.49% with the highest removal achieved on day 12th (99.29%). As for Reactor B, the average COD removal was 95.52% with the highest removal achieved on day 11th with 99.64%. It was observed that increase of organic loading in Phase 2 resulted in decrease of removal efficiency of both reactors. In phase 2, removal efficiency of both Reactors A and B was 77.1 % and 79.08% respectively from the first day of the new loading. The average removal efficiency for Reactor A and Reactor B was 89.89% and 90.48% respectively. In comparison with Phase 1, the average removal efficiency for phase 2 was lower. The difference in COD removal efficiency of both phase 1 and phase 2 can

be attributed to concentration gradient. Interestingly, both Reactor A and Reactor B have highest removal efficiency of 94.34% on the 50^{th} and 52^{nd} day respectively.

From the overall results, effluent concentrations from both reactors were below the Malaysia DOE discharge limit for Standard "A" 120 mg/L. The overall removal efficiency of Reactor B is slightly but insignificantly better than Reactor A with less than 1%. Both reactors showed good performance in organic carbon removal. The average COD removal difference in Phase 1 and Phase 2 of both reactor is less than 5%. These results also indicate that change of organic loading did not affect COD removal efficiency significantly. This difference could be due to change in loading which requires both nitrifying bacteria and denitrifying bacteria to stabilize and grow in the new organic loading. Similar observation was also made by Zinatizadeh et al., (2006) and Chan et al., (2012) during the change of loading of their influent reactor.

4.3.2 Ammonia-Nitrogen Removal

Ammonia-Nitrogen removal experimental result were recorded and shown in **Figure 4.5** for both Phase 1 and Phase 2. During Phase 1, the average ammonia- nitrogen supply to both Reactor A and B is in average of 18.89 mg/L. For the period of first 14 days in Phase 1, the value of Ammonia-Nitrogen fluctuate vigorously. However, after the addition of sufficient alkalinity, the influent concentration decreased and were consistent thereafter throughout the phase. This produce an influent average ammonia-nitrogen concentration of 9.46 mg/L simulating the composition of the low strength untreated domestic wastewater characteristic adopted from Metcalf and Eddy, (2013). On the other hand, average ammonia-nitrogen applied to both Reactor A and Reactor B in Phase 2 was 24.3 mg/L.

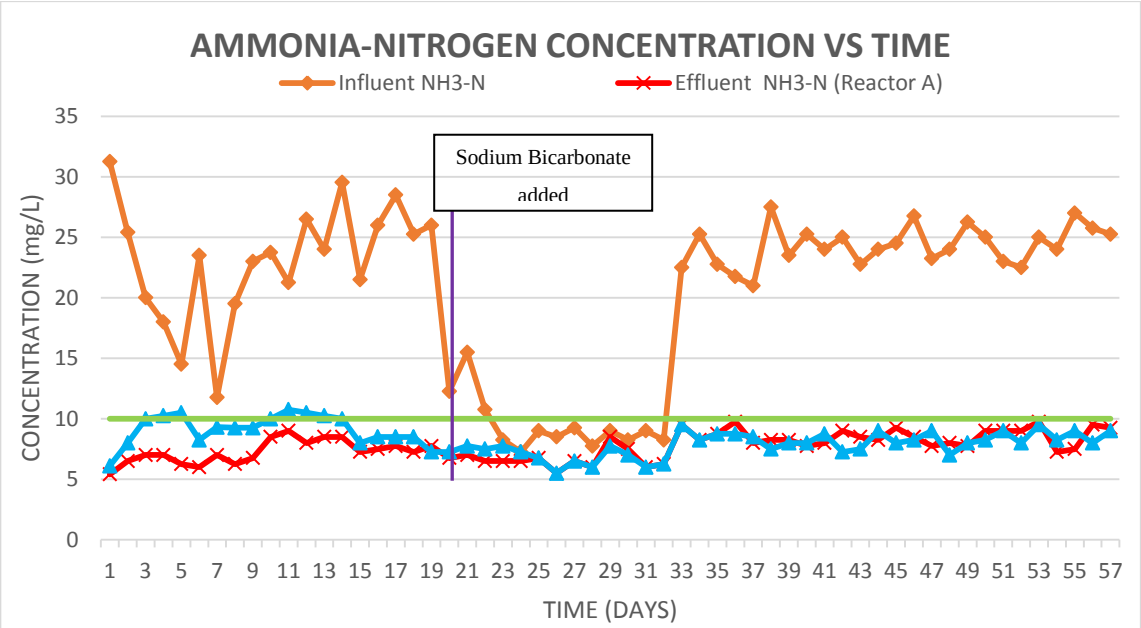

Figure 4.5 Ammonia Nitrogen Concentration Vs Time

Efficient ammonia-nitrogen removal were observed in the system at optimum influent pH range of 7.2-8.0. Through titration method for alkalinity, each mg of sodium bicarbonate used is found to produce 60 mg/L of alkalinity. Theoretically, every mg of ammonia oxidized consumes 7.07-7.14 mg of alkalinity. Therefore, the system required a minimum additional alkalinity of 118.5 mg/L. Thus, the system was provided with excess alkalinity of 120 mg/L to compensate for alkalinity shortage needed for the oxidation of the 8.5 mg/L of ammonia-nitrogen in the system. The result shows a slight decrease of ammonia-nitrogen in the system after alkalinity was added. Average influent alkalinity was about 260 mg/L. The effluent of Reactor A and Reactor B both consumed an average of about 133 mg/L and 113 mg/L of alkalinity.

Generally, during this period of research, DO was slowly adjusted to ensure a minimum concentration of 2 mg/L but not more than 3 mg/L in the aerobic zone. It was observed that when DO was below 2 mg/L at the aerobic zone, the removal of ammonia decreased significantly.

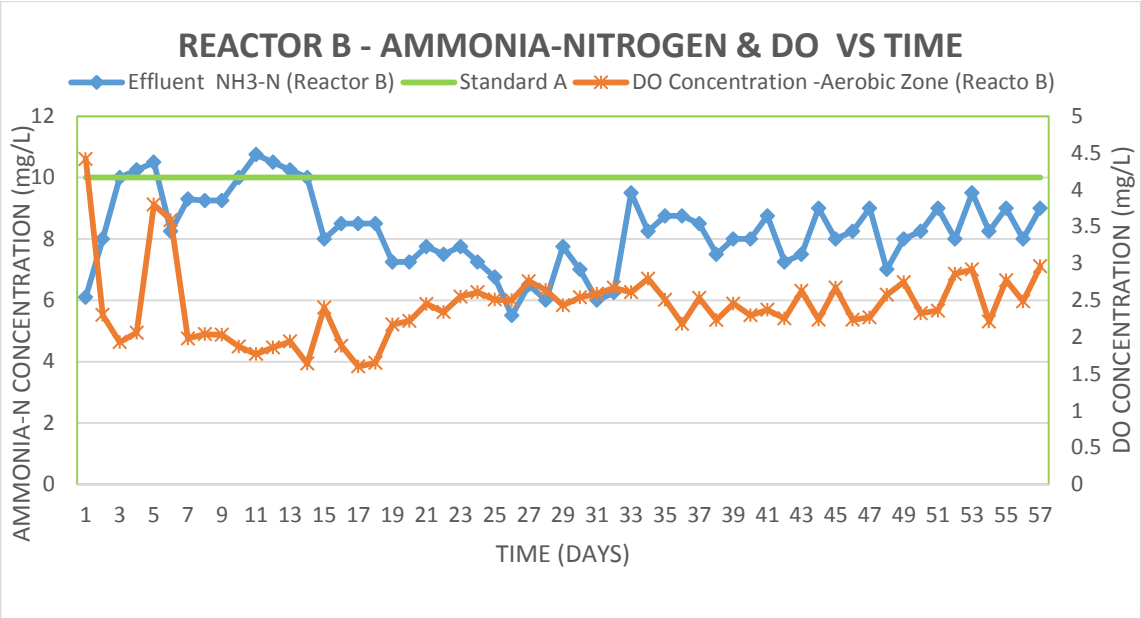

Figure 4.6 Reactor B - Ammonia-Nitrogen & DO Vs Time Graph

In **Figure 4.6** from day 7th to day 14th, effluent ammonia nitrogen concentration in Reactor B increased when DO concentration was below 2mg/L. However, when DO concentration was above 2 mg/L, effluent ammonia concentration decreased and the discharge limit of standard A was met.

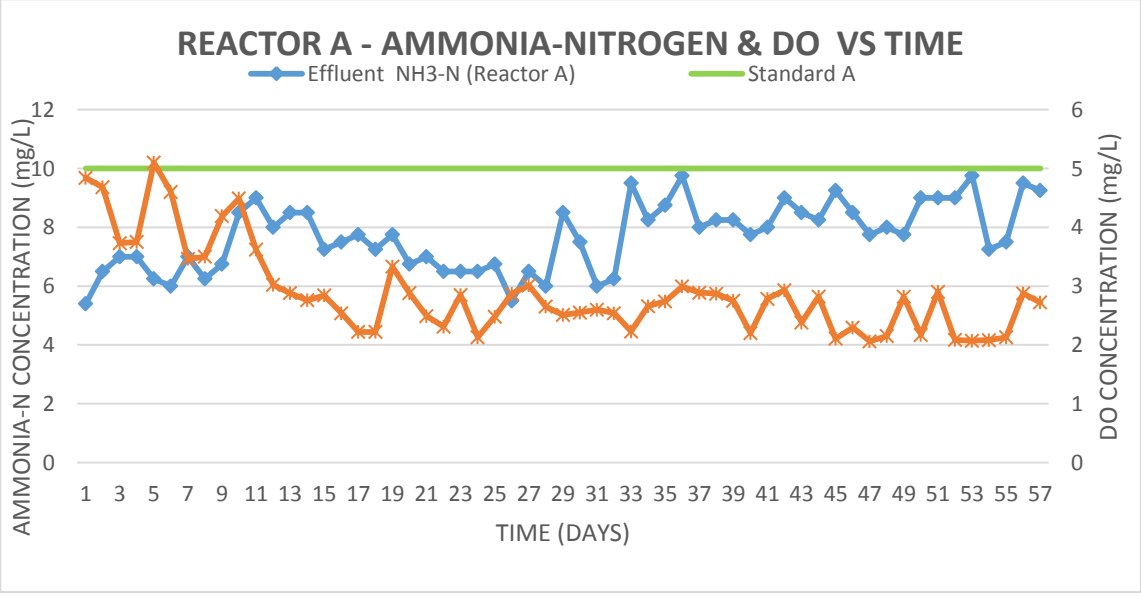

Figure 4.7 Reactor A - Ammonia-Nitrogen & DO Vs Time Graph

As shown in **Figure 4.7**, effluent ammonia concentration in Reactor A was within the Standard A limit when DO concentration was maintained above 2.0 mg/L consistently.

It was observed that, when DO concentration was below 2.0 mg/L, the Ammonia removal decreased. This is in line with the report of Yao et al.(2013) and was attributed to inhibition of ammonia-oxidizing ability at low DO (less than 2.0 mg/L).

Throughout Phase 1, average effluent ammonia concentration in Reactor A was about 8.98 mg/L. Average effluent ammonia concentration in Reactor B was about 8.67 mg/L after DO stabilized. The effluent produce in Phase 2 is a little bit better in comparison to Phase 1 with the discharge concentration of 8.55 mg/L and 8.36 mg/L for Reactor A and Reactor B respectively. This may be due to the additional source of carbon and consistent supply of alkalinity throughout the phase. Nevertheless, both reactor was in stable state in both phase and successfully produced a result within the Standard A limit of 10 mg/L.

4.3.3 Nitrate-Nitrogen Removal

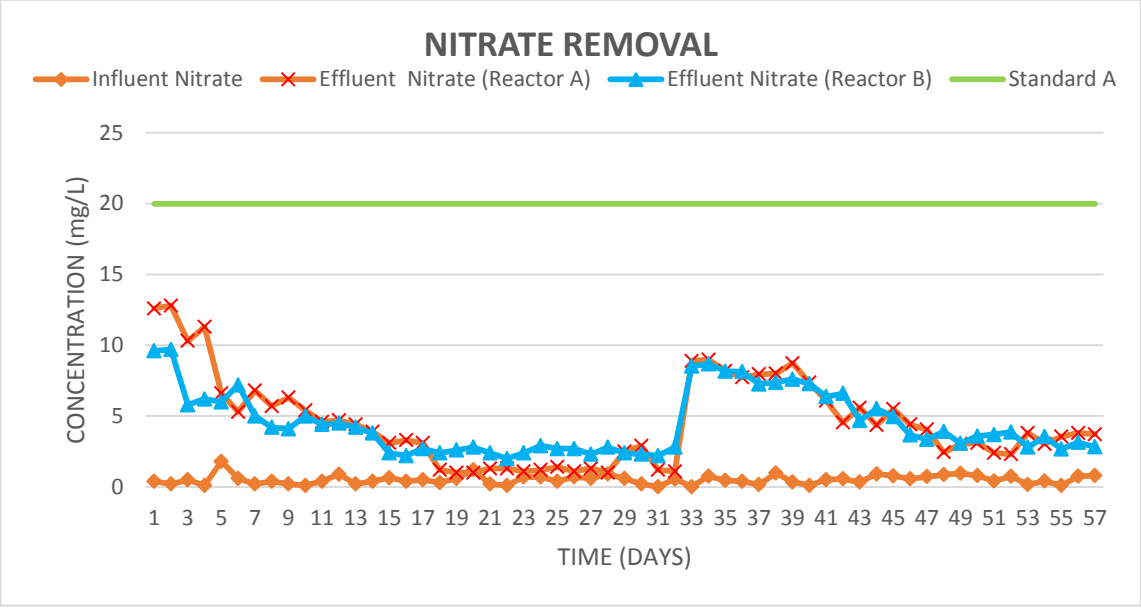

Figure 4.8 Nitrate Removal Graph

Figure 4.8 shows the graph of nitrate removal versus time. In Phase 1, Reactor A attained stable state on the 18th day while Reactor B was on the 15th day. Both Reactor A and B produce an average effluent nitrate concentration of 1.37 mg/L and 2.5 mg/L

respectively. While, in Phase 2, Reactor A and B both needed 11 days and 13 days respectively to attain stable state after the loading was increased. Average effluent concentration were 3.73 mg/L and 3.87 mg/L respectively.

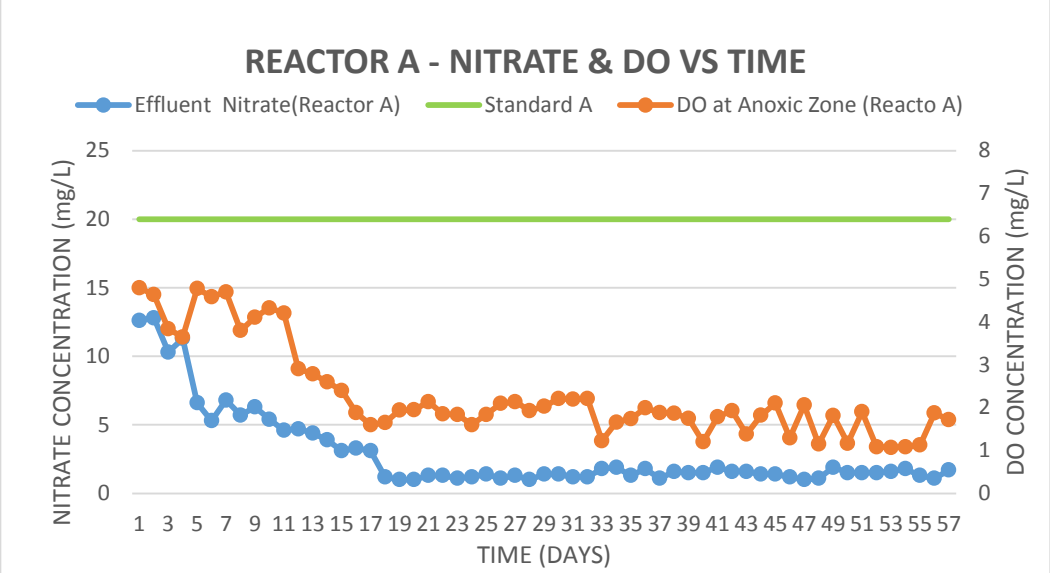

Figure 4.9 Reactor A - Nitrate & DO Vs Time Graph

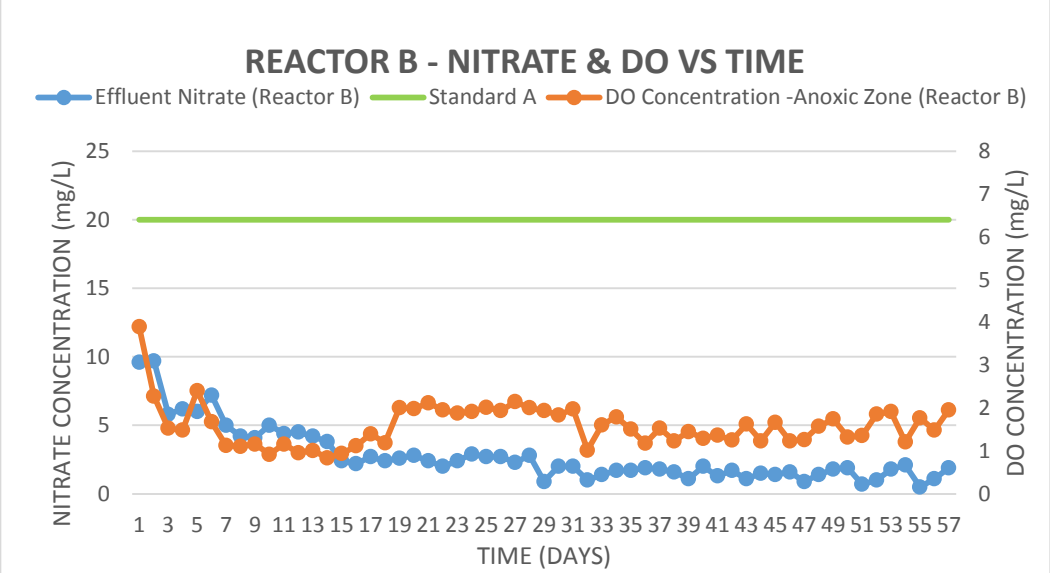

Figure 4.10 Reactor B - Nitrate & DO Vs Time Graph

Generally, during this period of research, DO was slowly adjusted to ensure a maximum concentration less than of 2 mg/L, virtually to achieve 0 mg/L in the aerobic zone. It was observed that when DO was above 2 mg/L at the anoxic zone, the removal of nitrate

decreased but not as significantly as ammonia. This can be seen in **Figure 4.9 and Figure 4.10** both reactor experience DO above 2 mg/L at several point even during the stable state (Reactor A: Day 21, 26,… / Reactor B: Day 40, 54) yet the discharge does not fluctuate as much as what experience by ammonia removal.

The average nitrate concentration discharge for Reactor A was slightly better in comparison to Reactor B for both phases. In comparison, this may be due to different configuration of influent inlet. As Reactor A having the influent flow inlet directly to the anoxic part, together with the internal recycle flow, more sludge is stirred and thus providing almost anoxic environment. On the opposite, Reactor B only experienced flow from the internal recycle inlet to mix the biomass at the bottom. Thus, providing less anoxic biomass and more anaerobic biomass. Still, both reactor manage to produce a result well within the Standard A limit of 20 mg/L.

4.3.4 Phosphorus Removal

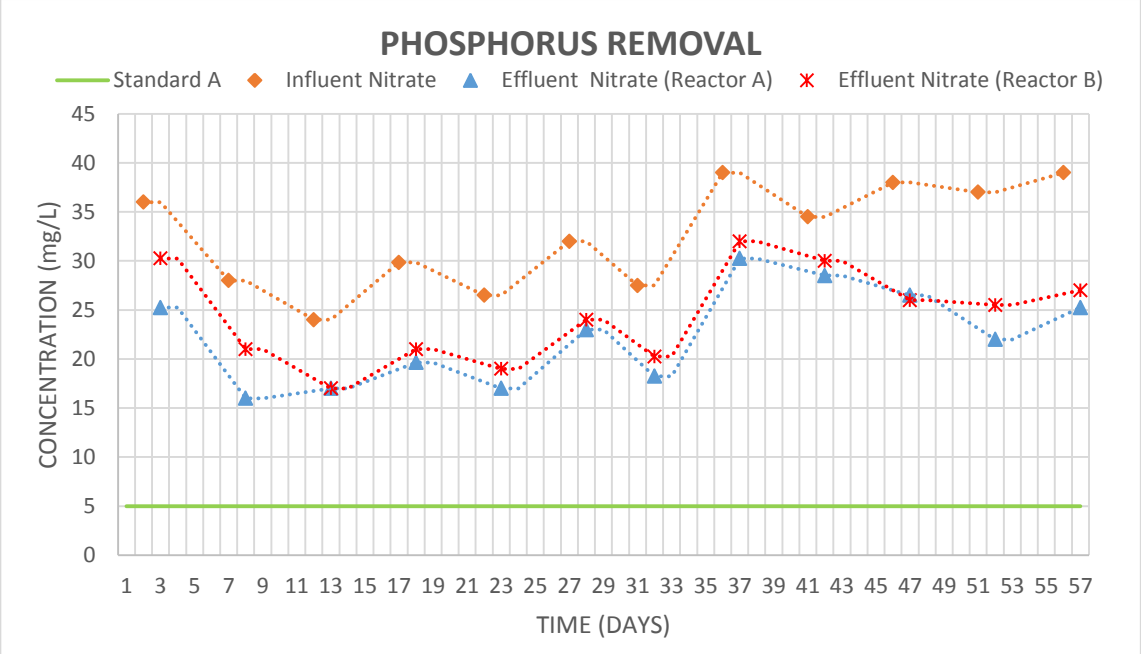

Figure 4.11 Phosphorus Removal Graph

From **Figure 4.11**, average removal for both reactor was about 25-30% which indicate existence of biomass in the system. However, the reactor was designed for only nitrogen

removal. As expected, effluent phosphorus concentration violated the DOE Malaysia discharge limit for River.

4.3.5 Formulation of Kinetics

To investigate the workability and performance of the activated sludge process, kinetic expression was used to illustrate the mathematical model. At steady state, MLVSS concentration is measured for each organic loading. MLVSS concentration during the steady state is tabulated in **Table 4.2.**

Table 4.2 MLSS in Steady-state Phase 1 and Phase 2

	MLVSS (mg/L)			
	Reactor A		Reactor B	
	Aerobic	Anoxic	Aerobic	Anoxic
Phase 1	742.857	2449.625	703.24	1873.85
Phase 2	1122.54	2842.246	1206.57	2134.85

The specific substrate utilization rate (μ) was examined to obtain the kinetics of substrate removal rate (k) for each reactor at different organic loading for each reactor using expression:

$$hrt = V/Q_o \quad (4.1)$$

$$\text{Specific substrate removal rate} = (S_o - S_e)/ X_{v,a}\, hrt\ (h^{-1}) \quad (4.2)$$

Figure 4.12 shows shows the specific substrate removal rate versus effluent. The slope of the plot indicates kinetics of substrate removal rate. From **Figure 4.12**, COD kinetics removal rate at aerobic zone is 0.0039 for Reactor A and 0.0014 for Reactor B. In the anoxic zone, kinetics substrate removal rate of Reactor B is observed to be 0.0035 while Reactor A indicate 0.0029. At aerobic zone, Reactor B basically have a higher substrate removal rate during phase 1 but lower substrate removal rate in phase 2 in comparison to Reactor A due to the kinetics gradient.

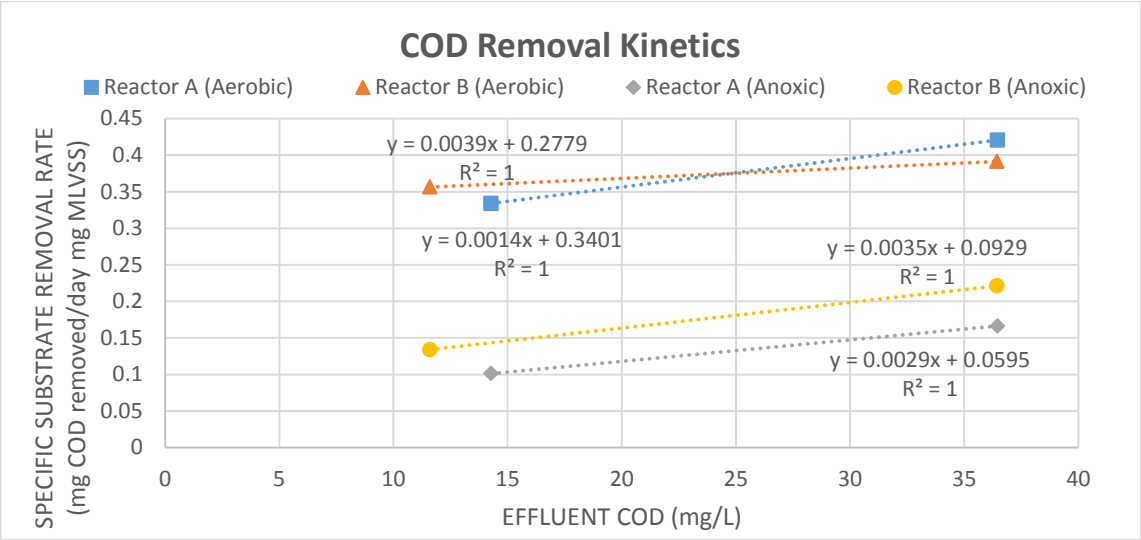

Figure 4.12 COD Removal Kinetics Graph

For nitrification, effluent ammonia is used at steady state with corresponding MLVSS to examine substrate utilization. From the **Figure 4.13**, the kinetics of substrate removal rate for Reactor A and Reactor B was 0.006 and 0.0057 respectively. Even though the kinetics of substrate removal rate is low, it still shows the presence of nitrification process in the system. Reactor A shows a better nitrification process in comparison to Reactor B.

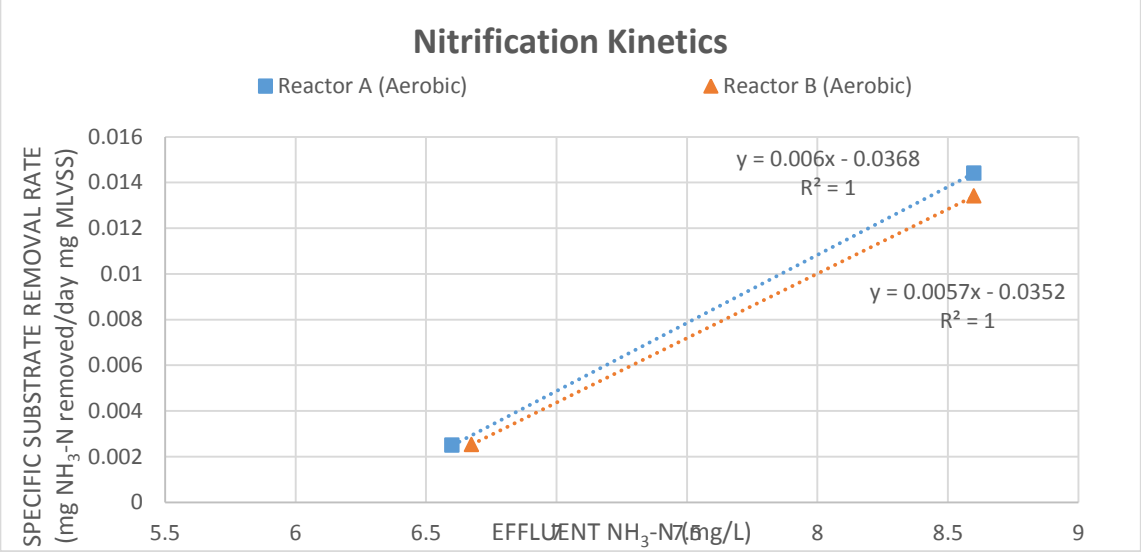

Figure 4.13 Nitrification Kinetics Graph

For denitrification, effluent nitrate is used at steady state with corresponding MLVSS to examine substrate utilization. The kinetics model is plot in **Figure 4.14**. Reactor A and Reactor B have a kinetics of removal rate value of 0.0829 and 0.1116 respectively. This indicate that Reactor B have a better substrate utilization process in comparison to Reactor A.

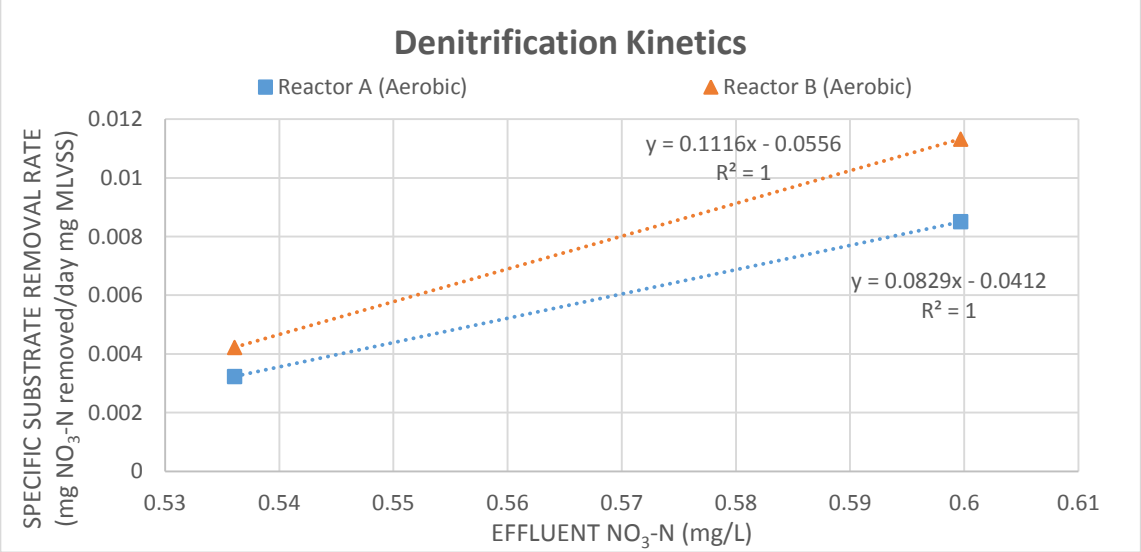

Figure 4.14 Denitrification Kinetics

Even though the kinetics of substrate removal of COD, nitrification and denitrification is quite low, nevertheless it still indicate that the reactor is capable in treating wastewater by reducing respective substrate accordingly.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Two reactor with different configuration is studied in this research. As for Reactor A, the inlet of the influent is set to be at the anoxic zone while Reactor B is on the aerobic zone of the reactor with same influent flow rate of 5L/day, SRT of 25 days, HRT of 24 hours with internal recycle rate of 15 L/day. The research is divided into two phase with different loading to determine the kinetics of activated sludge and the reactor performance.

During Phase 1, average influent concentration for COD and ammonia are 262 mg/L, and 9.46 mg/L respectively. For Reactor A, COD removal efficiency was about 94.49%. Whereas effluent concentration for ammonia and nitrate was 8.98mg/L and 1.37 mg/L. As for Reactor B, an average removal efficiency of 95.52% for COD, and effluent concentration of 8.67mg/l and 2.5 mg/L of ammonia and nitrate respectively. In Phase 1, Reactor B shows a better average removal of COD and ammonia, but slightly lower removal of nitrate in comparison to Reactor A.

In Phase 2, the average influent concentration of COD and ammonia are 508.76 mg/L and 24.3 mg/L respectively. For Reactor A, the average removal efficiency of COD is 89.89% while the concentration of ammonia and nitrate is 8.55 mg/L and 3.73 mg/L respectively. While Reactor B have an average COD removal efficiency of 90.48% with ammonia and nitrate concentration of 8.36 mg/L and 3.87 mg/L respectively. Likewise, Reactor B shows a better removal for COD and ammonia, but slightly lower removal of nitrate in comparison to Reactor A.

Kinetics performance of Reactor A and Reactor B is both shown in the result section. The kinetics substrate of removal rate for COD, nitrification and denitrification for Reactor A was 0.0014, 0.006 and 0.0829 respectively. On the other hand, Reactor B

kinetics substrate of removal rate for COD, nitrification and denitrification was 0.0039, 0.0057 and 0.1116 respectively. This indicate that ISA reactor is fully functioning and capable in treating the wastewater by reducing the respective substrate.

5.2 Recommendations

Due to lack of time, a comprehensive research on the kinetics model of ISA reactor cannot be carried out. Thus, a complete research focusing on the kinetics modelling should be design with longer period of research and varies organic loading. This is to ensure a more accurate and comprehensive result is obtain.

Moreover, the reactor can be further improved with the addition of a clarifier. This is to prevent biomass washout from the aerobic zone. Due to the flow from bottom to top at the anoxic part, sometimes the bacteria been wash out together with the effluent thus compromising the result of the research.

In addition, the design of influent and internal recycle inlet to the bottom of the anoxic part can be further improve. A small tube covering large area of the anoxic zone may result in more complete mix in comparison to now which only one (Reactor B) or two (Reactor A) big inlet at the middle of the anoxic zone. This may provide more effective mixing in the zone.

This study has great benefit to society and the environment. The integrated sequential anoxic-aerobic (ISA) reactor may be an effective solution in integrating two treatment methods of different environments (aerobic and anoxic) into a single entity. From the overall result, this reactor proves to be efficient in removing organic matter and nutrients. However, since this study was carried out using low and medium strength of wastewater, further studies could be conducted using high strength of wastewater to determine whether it is achievable to produce an effluent within the D.O.E Malaysia *Environmental Quality (Sewage) Regulations 2009* discharge standards.

References

Anglin, M. (2014, February 6). *What is Wastewater Treatment?* Retrieved from wiseGEEK: http://www.wisegeek.com/what-is-wastewater-treatment.htm

Anthonisen, A. C., Loehr, R. C., Prakasam, T. B., & Srinath, E. G. (1976). Inhibition of Nitrification by Ammonia and Nitrous Acid. *Water Pollution Control Federation, 48(5)*, 835-852.

Carrera, J., Bazeza, J. A., Vicent, T., & Lafuente, J. (2003). Biological Nitrogen Removal of High-Stregth Ammonium Industrial Wastewater with Two-Sludege System. *Water Research, 37*, 4211-4221.

Chan, Y. J., Chong, M. F., & Law, C. L. (2012). An integrated anaerobic-aerobic bioreactor (IAAB) for the treatment of palm oil mill effluent (POME): Start-up and steady state performance. *Process Biochemistry*, 485-495.

Chen, F. Y., Liu, Y. Q., Tay, J. H., & Ning, P. (2013). Alternating Anoxic/oxic Condition Combined with Step-feeding Mode for Nitrogen Removal in Granular Sequencing Batch Reactors (GSBRs). *Separation and Purification Technology, 105*, 63–68.

Ding, A., Qu, F., Liang, H., Ma, J., Han, Z., Yu, H., & Li, G. (2013). A Novel Integrated Vertical Membrane Bioreactor (IVMBR) for Removal of Nitrogen from Synthetic Wastewater/Domestic Sewage. *Chemical Engineering Journal, 223*, 908-914.

Ding, D., Feng, C., Jin, Y., Hao, C., Zhao, Y., & Suemura, T. (2011). Domestic Sewage Treatment in a Sequencing Batch Biofilm Reactor (SBBR) with an Intelligent Controlling System. *Desalination, 276*, 260–265.

Du, R., Peng, Y., Cao, S., Wu, C., Weng, D., Wang, S., & He, J. (2014). Advance nitrogen removal with simultaneoues Anammox and denitrification in sequencing batch reactor. *Bioresource Technology, 162*, 316-322.

Duchene, P., Cotteus, E., & Capela, S. (2001). Applying Fine Bubble Aeration to Small Aeration Tanks. *Water Science and Technology, 44*(2-3), 203-210.

El-Bourawi, M., Khayet, M., Ma, R., Ding, Z., Li, Z., & Zhang, X. (2007). Application of Vacuum Membrane Distillation for Ammonia Removal. *Journal of Membrane Science, 301*, 200-209.

Goldstein, e., & Peterson, R. (2006, July). *Understanding Algae*. Retrieved from Natural Environmental Systems, LLC: http://www.naturalenviro.com/Article.php?ArticleSKU=Understanding-Algae

Halling-Sorensen, B., & Jorgensen, S. (1993). *The Removal of Nitrogen Compounds from Wastewater.* Amsterdam, The Netherlands: Elsevier Science Publishers B.V.

Jetten, M. S., Logemann, S., Muyzer, G., Robertson, L. A., Vries, S., Loosdrecht, M. C., & Kuenen, J. G. (1997). Novel Principles in the Microbial Conversion of Nitrogen Compounds. *Antonie van Leeuwenhoek, 71*, 75-93.

Karahan, Ö. (2010). Inhibition Effect of Linear Alkylbenzene Sulphonates on the Biodegradation Mechanisms of Activated Sludge. *Bioresource Technology, 101*, 92-97.

Knobeloch, L., Saina, B., Hogan, A., Postle, J., & Anderson, H. (2000). Blur Babies and Nitrate-Contaminated Well Water. *Environmental Health Perspective, 108(7)*, 675-678.

Lee, H.-J., Bae, J.-H., & Cho, K.-M. (2001). Simultaneous Nitrification and Denitrification in a Mixed Methanotrophic Culture. *Biotechnology Letters, 23*, 935-941.

Madigan, Martinko, & Parker. (2000). *Biology of Micoorganisms, 9th edition.* Saddle River, NJ: Prentice Hall.

Metcalf & Eddy, Inc. (2013). *Wastewater Engineering: Treatment and Reuse, 4th ed.* New York: McGraw-Hill.

Moura, R. B., Damianovic, M. H., & Foresti, E. (2012). Nitrogen and Carbon Removal from Synthetic Wastewater in a Vertical Structured-Bed Reactor Under Intermittent Aeration. *Journal of Environmental Management, 98*, 163-167.

Muller, A., Wentzel, M., Loewenthal, R., & Ekama, G. (2003). Heterotroph Anoxic Yield in Anoxic Aerobic Activated Sludge Systems treating Municipal Wastewater. *Water Res, 37(10),* 2435-2441.

Rieger, L., Alex, J., Gujer, W., & Siegrist, H. (2006). Modelling of Aeration Systems at Wastewater Treatment Plants. *Water Science and Technology*, *53*(4-5), 439-447.

S.R.M.Kutty, M.H.Isa, & L.C.Leong. (2011). Removal of Ammonia-Nitrogen and Nitrate by Modified Conventional Activated-Sludge System to Meet New D.O.E Regulations. *IPCBEE, 12*, 103-107.

Strous, M., Heijnen, J., Kuenen, J. G., & Jetten, M. (1998). The Sequencing Batch Reactor as a Powerful Tool for the Study of Slowly Growing Anaerobic Ammonium-Oxidizing Microorganisms. *Appl Microbiol Biotechnol, 50*, 589-596.

Tan, X., Tan, S., Teo, W., & Li, K. (2006). Polyvinylidene FLuoride (PVDF) hollow fibre membranes for ammonia removal from water. *Journal of Membrane Science, 271*, 59-68.

Vaiopoulou, E., Melidis, P., & Aivasidis, A. (2007). An Activated Sludge Tratment Plant for Integrated Removal of Carbon, Nitrogen and Phosphorus. *ScienceDirect, 211*, 192-199.

Wang, L. K., Hung, Y.-T., & Shammas, N. K. (2007). *Advanced Physicochemical Treatment Processes.* New Jersey: Humana Press Inc.

Washington State Department of Health. (2005). *Nitrogen Reducing Technologies for Onsite Wastewater Treatment System.* Washington: Puget Sound Action Team.

Xiuhong, Z., Jiti, Z., Haiyan, G., Yuanyuan, G., Guangfei, L., & Lihong, Z. (2007). Nitrogen removal performance in a novel combined biofilm reactor. *Process Biochemistry, 42*, 620-626.

Yao, Y.-C., Zhang, Q.-L., Liu, Y., & Liu, Z.-P. (2013). Simultaneous Removal of Organic Matter and Nitrogen by Heterotrophic Nitrifying- Aerobic Denitrifying Bacterial Strain in a Membrane Bioreactor. *Bioresource Technology, 143*, 83-87.

Yoo, H., Ahn, K.-H., Lee, H.-J., Lee, K.-H., Kwak, Y.-J., & Song, K.-G. (1999). Nitrogen Removal from Synthetic Wastewater by SImultaneous Nitrification and Denitrification (SND) Via Nitrite in an Intermittently-Aerated Reactor. *Water Res., 33*, 145-154.

Zinatizadeh, A., Mohamed, A., Najafpour, G., Hasnain Isa, M., & Nasrollahzadeh, H. (2006). Kinetic evaluation of palm oil mill effluent digestion in a high rate up-flow anaerobic sludge fixed film bioreactor. *Process Biochemistry, 41*, 1038-1046.

APPENDIX

APPENDIX

Appendix A: Influent/Effluent Characteristics

Appendix B: Analysis of Data

Appendix A: Influent/Effluent Characteristics

COD

NO	DATE	Influent COD, mg/L	Effluent COD , mg/L (Reactor A)	Effluent COD , mg/L (Reactor B)
1	20-05-14	118	38	28
2	21-05-14	218	102	84
3	22-05-14	236	104	81
4	23-05-14	225	69	77
5	26-05-14	229	12	41
6	27-05-14	280	21	18
7	28-05-14	296	4	4
8	29-05-14	283	13	12
9	30-05-14	230	12	16
10	02-06-14	287	4	6
11	03-06-14	268	5	2
12	04-06-14	280	2	1
13	05-06-14	245	6	4
14	06-06-14	262	6	6
15	09-06-14	246	12	9
16	10-06-14	220	9	14
17	11-06-14	277	7	7
18	12-06-14	294	10	15
19	13-06-14	307	12	14
20	16-06-14	242	13	14
21	17-06-14	237	12	12
22	18-06-14	284	14	11
23	19-06-14	244	21	16
24	20-06-14	237	24	14
25	23-06-14	241	19	18
26	24-06-14	278	23	15
27	25-06-14	291	21	15
28	26-06-14	247	19	9
29	01-07-14	271	22	17
30	02-07-14	269	24	14
31	03-07-14	248	22	15
32	04-07-14	269	25	14
33	07-07-14	459	105	96
34	08-07-14	507	108	87

35	09-07-14	523	94	77
36	10-07-14	496	86	81
37	11-07-14	550	73	74
38	14-07-14	513	54	49
39	15-07-14	510	65	43
40	16-07-14	493	56	46
41	17-07-14	518	48	50
42	18-07-14	488	42	41
43	21-07-14	488	40	50
44	22-07-14	513	40	43
45	23-07-14	495	41	47
46	24-07-14	536	40	33
47	25-07-14	462	35	30
48	28-07-14	541	34	35
49	29-07-14	512	34	35
50	30-07-14	530	30	34
51	31-07-14	468	37	35
52	01-08-14	530	40	30
53	04-08-14	479	36	39
54	05-08-14	497	40	39
55	06-08-14	546	37	39
56	07-08-14	516	30	32
57	08-08-14	549	33	39.00

NH_3-N

No	Date	Influent NH_3-N, mg/L	Effluent NH_3-N, mg/L (Reactor A)	Effluent NH_3-N, mg/L (Reactor B)
1	20-05-14	31.25	5.4	6.1
2	21-05-14	25.4	6.5	8
3	22-05-14	20	7	10
4	23-05-14	18	7	10.25
5	26-05-14	14.5	6.25	10.5
6	27-05-14	23.5	6	8.25
7	28-05-14	11.75	7	9.3
8	29-05-14	19.5	6.25	9.25
9	30-05-14	23	6.75	9.25
10	02-06-14	23.75	8.5	10

11	03-06-14	21.25	9	10.75
12	04-06-14	26.5	8	10.5
13	05-06-14	24	8.5	10.25
14	06-06-14	29.54	8.5	10
15	09-06-14	21.5	7.25	8
16	10-06-14	26	7.5	8.5
17	11-06-14	28.5	7.75	8.5
18	12-06-14	25.25	7.25	8.5
19	13-06-14	26	7.75	7.25
20	16-06-14	12.25	6.75	7.25
21	17-06-14	15.5	7	7.75
22	18-06-14	10.75	6.5	7.5
23	19-06-14	8.25	6.5	7.75
24	20-06-14	7.25	6.5	7.25
25	23-06-14	9	6.75	6.75
26	24-06-14	8.5	5.5	5.5
27	25-06-14	9.25	6.5	6.5
28	26-06-14	7.75	6	6
29	01-07-14	9	8.5	7.75
30	02-07-14	8.25	7.5	7
31	03-07-14	9	6	6
32	04-07-14	8.25	6.25	6.25
33	07-07-14	22.5	9.5	9.50
34	08-07-14	25.25	8.25	8.25
35	09-07-14	22.75	8.75	8.75
36	10-07-14	21.75	9.75	8.75
37	11-07-14	21	8	8.5
38	14-07-14	27.5	8.25	7.5
39	15-07-14	23.5	8.25	8
40	16-07-14	25.25	7.75	8
41	17-07-14	24	8	8.75
42	18-07-14	25	9	7.25
43	21-07-14	22.75	8.5	7.5
44	22-07-14	24	8.25	9
45	23-07-14	24.5	9.25	8
46	24-07-14	26.75	8.5	8.25
47	25-07-14	23.25	7.75	9
48	28-07-14	24	8	7
49	29-07-14	26.25	7.75	8
50	30-07-14	25	9	8.25
51	31-07-14	23	9	9

52	01-08-14	22.5	9	8
53	04-08-14	25	9.75	9.5
54	05-08-14	24	7.25	8.25
55	06-08-14	27	7.5	9
56	07-08-14	25.75	9.5	8
57	08-08-14	25.25	9.25	9

NO_3-N

No	Date	Influent Nitrate, mg/L	Effluent Nitrate, mg/L (Reactor A)	Effluent Nitrate, mg/L (Reactor B)
1	20-05-14	0.4	12.6	9.6
2	21-05-14	0.2	12.8	9.7
3	22-05-14	0.5	10.3	5.8
4	23-05-14	0.1	11.3	6.2
5	26-05-14	1.8	6.6	6
6	27-05-14	0.6	5.3	7.2
7	28-05-14	0.2	6.8	5
8	29-05-14	0.4	5.7	4.2
9	30-05-14	0.2	6.3	4.1
10	02-06-14	0.1	5.4	5
11	03-06-14	0.39	4.6	4.4
12	04-06-14	0.89	4.7	4.5
13	05-06-14	0.2	4.4	4.2
14	06-06-14	0.4	3.9	3.8
15	09-06-14	0.64	3.1	2.4
16	10-06-14	0.4	3.3	2.2
17	11-06-14	0.5	3.1	2.7
18	12-06-14	0.3	1.2	2.4
19	13-06-14	0.6	1	2.6
20	16-06-14	1.2	1	2.8
21	17-06-14	0.2	1.3	2.4
22	18-06-14	0.1	1.3	2
23	19-06-14	0.7	1.1	2.4
24	20-06-14	0.7	1.2	2.9
25	23-06-14	0.4	1.4	2.7
26	24-06-14	0.7	1.1	2.7
27	25-06-14	0.6	1.3	2.3
28	26-06-14	0.9	1	2.8

29	01-07-14	0.6	2.5	2.4
30	02-07-14	0.2	2.9	2.3
31	03-07-14	0.01	1.2	2.2
32	04-07-14	0.6	1.1	2.8
33	07-07-14	0.0	8.9	8.5
34	08-07-14	0.76	9.0	8.7
35	09-07-14	0.46	8.2	8.2
36	10-07-14	0.4	7.7	8.1
37	11-07-14	0.15	8.0	7.3
38	14-07-14	0.97	8.0	7.4
39	15-07-14	0.4	8.7	7.6
40	16-07-14	0.1	7.4	7.3
41	17-07-14	0.50	6.1	6.4
42	18-07-14	0.57	4.5	6.6
43	21-07-14	0.3	5.6	4.7
44	22-07-14	0.92	4.4	5.5
45	23-07-14	0.8	5.5	5.0
46	24-07-14	0.57	4.4	3.7
47	25-07-14	0.72	4.0	3.4
48	28-07-14	0.86	2.4	3.9
49	29-07-14	0.96	3.0	3.1
50	30-07-14	0.8	3.1	3.6
51	31-07-14	0.42	2.4	3.7
52	01-08-14	0.7	2.3	3.9
53	04-08-14	0.17	3.8	2.8
54	05-08-14	0.4	3.0	3.6
55	06-08-14	0.10	3.6	2.7
56	07-08-14	0.75	3.8	3.1
57	08-08-14	0.8	3.7	2.8

PHOSPHORUS

No	Date	Influent Phosphorus, mg/L	Effluent Phosphorus, mg/L (Reactor A)	Effluent Phosphorus, mg/L (Reactor B)
1	20-05-14			
2	21-05-14			
3	22-05-14	36	25.25	30.25
4	23-05-14			
5	26-05-14			

6	27-05-14			
7	28-05-14			
8	29-05-14	28	16	21
9	30-05-14			
10	02-06-14			
11	03-06-14			
12	04-06-14			
13	05-06-14	24	17	17
14	06-06-14			
15	09-06-14			
16	10-06-14			
17	11-06-14			
18	12-06-14	29.84	19.64	21
19	13-06-14			
20	16-06-14			
21	17-06-14			
22	18-06-14			
23	19-06-14	26.5	17	19
24	20-06-14			
25	23-06-14			
26	24-06-14			
27	25-06-14			
28	26-06-14	32	23	24
29	01-07-14			
30	02-07-14			
31	03-07-14			
32	04-07-14	27.5	18.25	20.25
33	07-07-14			
34	08-07-14			
35	09-07-14			
36	10-07-14			
37	11-07-14	39	30.25	32
38	14-07-14			
39	15-07-14			
40	16-07-14			
41	17-07-14			
42	18-07-14	34.5	28.5	30
43	21-07-14			
44	22-07-14			
45	23-07-14			
46	24-07-14			

47	25-07-14	38	26.5	26
48	28-07-14			
49	29-07-14			
50	30-07-14			
51	31-07-14			
52	01-08-14	37	22	25.5
53	04-08-14			
54	05-08-14			
55	06-08-14			
56	07-08-14			
57	08-08-14	39	25.25	27

Appendix B: Analysis of Data

COD Removal Efficiency

No	Date	Reactor A Removal Efficiency	Reactor B Removal Efficiency
1	20-05-14	67.79661	76.27119
2	21-05-14	53.21101	61.46789
3	22-05-14	55.9322	65.67797
4	23-05-14	69.33333	65.77778
5	26-05-14	94.75983	82.09607
6	27-05-14	92.5	93.57143
7	28-05-14	98.64865	98.64865
8	29-05-14	95.40636	95.75972
9	30-05-14	94.78261	93.04348
10	02-06-14	98.60627	97.90941
11	03-06-14	98.13433	99.25373
12	04-06-14	99.28571	99.64286
13	05-06-14	97.55102	98.36735
14	06-06-14	97.70992	97.70992
15	09-06-14	95.12195	96.34146
16	10-06-14	95.90909	93.63636
17	11-06-14	97.47292	97.47292
18	12-06-14	96.59864	94.89796
19	13-06-14	96.09121	95.43974
20	16-06-14	94.6281	94.21488
21	17-06-14	94.93671	94.93671
22	18-06-14	95.07042	96.12676
23	19-06-14	91.39344	93.44262
24	20-06-14	89.87342	94.09283
25	23-06-14	92.11618	92.53112
26	24-06-14	91.72662	94.60432
27	25-06-14	92.78351	94.84536
28	26-06-14	92.30769	96.35628
29	01-07-14	91.88192	93.72694
30	02-07-14	91.07807	94.79554
31	03-07-14	91.12903	93.95161
32	04-07-14	90.70632	94.79554
33	07-07-14	77.12418	79.08497
34	08-07-14	78.69822	82.84024

35	09-07-14	82.02677	85.27725
36	10-07-14	82.66129	83.66935
37	11-07-14	86.72727	86.54545
38	14-07-14	89.47368	90.44834
39	15-07-14	87.2549	91.56863
40	16-07-14	88.64097	90.66937
41	17-07-14	90.73359	90.34749
42	18-07-14	91.39344	91.59836
43	21-07-14	91.80328	89.7541
44	22-07-14	92.20273	91.61793
45	23-07-14	91.71717	90.50505
46	24-07-14	92.53731	93.84328
47	25-07-14	92.42424	93.50649
48	28-07-14	93.71534	93.5305
49	29-07-14	93.35938	93.16406
50	30-07-14	94.33962	93.58491
51	31-07-14	92.09402	92.52137
52	01-08-14	92.45283	94.33962
53	04-08-14	92.48434	91.85804
54	05-08-14	91.95171	92.15292
55	06-08-14	93.22344	92.85714
56	07-08-14	94.18605	93.79845
57	08-08-14	93.98907	92.89617

COD REMOVAL KINETICS

	1	2	3	4	5	6	7	
	Reactor No	Influent Average Concentration COD, S_o (mg/L)	Effluent Average Concentration COD, S_e (mg/L)	MLVSS, $X_{v,a}$ (mg/L)	Q_o (L/h)	Residence time, hrt (h)	$S_o - S_e$ (mg/L)	
A	1	508.76	36.47	1122.54	5	1	472.29	
	2	262.28	14.28	742.857	5	1	248	
B	1	508.76	36.43	1206.57	5	1	472.33	
	2	262.28	11.6	703.24	5	1	250.68	
A	1	508.76	36.47	2842.246	5	1	472.29	2
	2	262.28	14.28	2449.625	5	1	248	2
B	1	508.76	36.43	2134.85	5	1	472.33	
	2	262.28	11.6	1873.85	5	1	250.68	

		$(S_o - S_e)/ X_{v,a}$ hrt (h^{-1})	S_e
Aerobic	Reactor A	0.420733	36.47
		0.333846	14.28
	Reactor B (Aerobic)	0.391465	36.43
		0.356464	11.6
Anoxic	Reactor A	0.166168	36.47
		0.10124	14.28
	Reactor B (Anoxic)	0.221247	36.43
		0.133778	11.6

NITRIFICATION KINETICS

NH_3-N

	1	2	3	4	5	6	7	8	9
	Reactor No	Influent Average Concentration NH_3-N, S_o (mg/L)	Effluent Average Concentration COD, S_e (mg/L)	MLVSS, $X_{v,a}$ (mg/L)	Q_o (L/h)	Residence time, hrt (h)	$S_o - S_e$ (mg/L)	$X_{v,a}$ hrt (mgh/L)	$(S_o - S_e)/ X_{v,a}$ hrt (h^{-1})
A	1	24.775	8.6	1122.54	5	1	16.175	1122.54	0.014409
	2	8.45	6.6	742.857	5	1	1.85	742.857	0.00249
B	1	24.775	8.6	1206.57	5	1	16.175	1206.57	0.013406
	2	8.45	6.675	703.24	5	1	1.775	703.24	0.002524

	$(S_o - S_e)/ X_{v,a}$ hrt (h^{-1})	S_e
Reactor A (Aerobic)	0.014409	8.6
	0.00249	6.6
Reactor B (Aerobic)	0.013406	8.6
	0.002524	6.675

DENITRIFICATION KINETICS

NO_3-N

	1	2	3	4	5	6	7	8	
	Reactor No	Influent Average Concentration NO_3-N, S_o (mg/L)	Effluent Average Concentration COD, S_e (mg/L)	MLVSS, $X_{v,a}$ (mg/L)	Q_o (L/h)	Residence time, hrt (h)	$S_o - S_e$ (mg/L)	$X_{v,a}$ hrt (mgh/L)	$(S_o - S_e)$ $X_{v,a}$ hrt (h^{-1})
A	1	24.775	0.5997	2842.246	5	1	24.1753	2842.246	0.00850
	2	8.45	0.5361	2449.625	5	1	7.9139	2449.625	0.00323
B	1	24.775	0.5997	2134.85	5	1	24.1753	2134.85	0.01132
	2	8.45	0.5361	1873.85	5	1	7.9139	1873.85	0.00422

	$(S_o - S_e)/ X_{v,a}$ hrt (h^{-1})	S_e
Reactor A (Aerobic)	0.008506	0.5997
	0.003231	0.5361
Reactor B (Aerobic)	0.011324	0.5997
	0.004223	0.5361